5 Newton's Second Law of Motion—Force and Acceleration

Chapter 5 develops the relation that acceleration is proportional to force and inversely proportional to mass ($a = F/m$). This relation is applied to falling bodies, with and without air resistance.

The thrill of a roller coaster ride comes from the accelerations experienced.

Kick a football and it moves. Its path through the air is not a straight line—it curves downward due to gravity. Catch the ball and it stops. Most of the motion we see undergoes change. Most things start up, slow down, or curve as they move. The previous chapter covered objects at rest or moving at constant velocity. There was no net force acting on these objects. This chapter covers the more common cases in which there is a *change* in motion—that is, accelerated motion.

Recall from Chapter 2 that acceleration describes how quickly motion changes. Specifically, it is the change in velocity per certain time interval. In shorthand notation,

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time interval}}$$

This is the definition of acceleration.* This chapter focuses on the *cause* of acceleration: *force.*

Figure 5.1 ▲
Kick a football and it neither remains at rest nor moves in a straight line.

5.1 Force Causes Acceleration

Consider an object at rest, such as a hockey puck on ice. Apply a force and it starts to move. Since the puck was not moving before, it has accelerated—it has changed its motion. When the hockey stick is no longer pushing it, the puck moves at constant velocity. Apply another force by striking the puck again, and again the motion changes. The puck accelerates—force causes acceleration.

Figure 5.2 ▲
Puck about to be hit.

* The Greek letter Δ (delta) is often used as a symbol for "change in" or "difference in." In delta notation, $a = \Delta v/\Delta t$, where Δv is the change in velocity and Δt is the change in time (the time interval).

Videotape: Show "Newton's Second Law" from the series *Conceptual Physics Alive!*

Force in this chapter is simply a push or a pull. We will look at this definition further in the next chapter (where it is treated as part of an interaction).

Distinguish between the symbol ~ (is directly proportional to) and the symbol = (is equal to).

Most often, the force we apply is not the only force acting on an object. Other forces may act as well. Recall from the previous chapter that the combination of forces acting on an object is the *net force.* Acceleration depends on the *net force.* To increase the acceleration of an object, you must increase the net force acting on it. This makes good sense. Double the force on an object and its acceleration doubles. If you triple the force, its acceleration triples, and so on. We say an object's acceleration is directly proportional to the net force acting on it. We write

$$\text{acceleration} \sim \text{net force}$$

The symbol ~ stands for "is directly proportional to."

5.2 Mass Resists Acceleration

Important Term

inversely

Push on an empty shopping cart. Then push equally hard on a heavily loaded shopping cart. The loaded shopping cart will accelerate much less than the empty cart. This shows that acceleration depends on the mass being pushed. The same force applied to twice as much mass results in only half the acceleration. For three times the mass, one-third the acceleration results. In other words, for a given force, the acceleration produced is *inversely proportional* to the mass. We write

$$\text{acceleration} \sim \frac{1}{\text{mass}}$$

Figure 5.3 ▲
The acceleration produced depends on the mass that is pushed.

By **inversely** we mean that the two values change in opposite directions. Mathematically we see that as the denominator increases, the whole quantity decreases. The quantity 1/100 is less than the quantity 1/10, for example.

5.3 Newton's Second Law

Important Term

Newton's second law

Newton was the first to realize that the acceleration produced when we move something depends not only on how hard we push or pull, but also on the object's mass. He came up with one of the most important rules of nature ever proposed, his second law of motion. **Newton's second law** states

> The acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.

Or, in equation form,

$$\text{acceleration} \sim \frac{\text{net force}}{\text{mass}}$$

The Best From Conceptual Physics Alive!

Force Causes Acceleration

Side 1
Chapter 23

Figure 5.4
The great acceleration of the racing car is due to its ability to produce large forces.

By using consistent units, such as newtons (N) for force, kilograms (kg) for mass, and meters per second squared (m/s^2) for acceleration, we get the exact equation

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}}$$

In briefest form, where a is acceleration, F is net force, and m is mass,

$$a = \frac{F}{m}$$

The acceleration is equal to the net force divided by the mass. From this relationship we see that doubling the net force acting on an object doubles its acceleration. Suppose instead that the mass is doubled. Then acceleration will be halved. If both the net force and the mass are doubled, the acceleration will be unchanged.

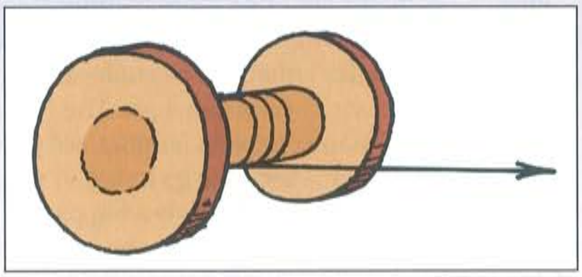
Interactive Physics™ Simulations: 7 *g* Forces and 9 Rocket Launch

Solving computational problems may be an easy way to *teach* physics. It is not, however, an easy way for many of your students to *learn* physics. (Schools abound with students who can crank out solutions but fail at Think and Explain questions.) Do *not* let your class be sidetracked into solving computational problems most of the time. Comprehension before calculation!

DOING PHYSICS

Acceleration, Which Way?

The net force acting on an object and its resulting acceleration are always in the same direction. You can demonstrate this with a spool of thread. If the spool is pulled horizontally by the thread to the right, in which direction will it roll? Does it make a difference whether the string is on the bottom or the top? Try it and you might be surprised.



Activity

The Best From Conceptual Physics Alive!

Newton's 2nd Law

Side 1
Chapter 24

Problem Solving

If we know the mass of an object in kilograms (kg) and its acceleration in meters per second per second (m/s^2), then the force will be expressed in newtons (N). One newton is the force needed to give a mass of one kilogram an acceleration of one meter per second squared. We can arrange Newton's second law to read

$$\text{force} = \text{mass} \times \text{acceleration}$$

$$1\ \text{N} = (1\ \text{kg})(1\ \text{m/s}^2)$$

We can see,

$$1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$$

The dot between kg and m/s^2 means that the units are multiplied together.

If we know two of the quantities in Newton's second law, we can calculate the third. For example, how much force, or thrust, must a 30 000-kg jet plane develop to achieve an acceleration of 1.5 m/s^2? We calculate

$$\begin{aligned} F &= ma \\ &= (30\,000\ \text{kg})(1.5\ \text{m/s}^2) \\ &= 45\,000\ \text{kg}\cdot\text{m/s}^2 \\ &= 45\,000\ \text{N} \end{aligned}$$

Suppose we know the force and the mass, and we want to find the acceleration. For example, what acceleration is produced by a force of 2000 N applied to a 1000-kg car? Using Newton's second law we find

$$a = \frac{F}{m} = \frac{2000\ \text{N}}{1000\ \text{kg}} = \frac{2000\ \text{kg}\cdot\text{m/s}^2}{1000\ \text{kg}} = 2\ \text{m/s}^2$$

If the force is 4000 N, what is the acceleration?

$$a = \frac{F}{m} = \frac{4000\ \text{N}}{1000\ \text{kg}} = \frac{4000\ \text{kg}\cdot\text{m/s}^2}{1000\ \text{kg}} = 4\ \text{m/s}^2$$

Doubling the force on the same mass simply doubles the acceleration.

Physics problems are often more complicated than these. We don't focus on solving complicated problems in this book. Instead we emphasize equations as guides to thinking about the relationships of basic physics concepts. The Plug and Chug section at the end of many chapters familiarizes you with equations, and the Problems sections go a step or two further for more challenge. Solving problems is a big part of more advanced physics courses. For now, learn the concepts! Then problem solving will be more meaningful.

Questions

1. If a car can accelerate at 2 m/s^2, what acceleration can it attain if it is towing another car of equal mass?
2. What kind of motion does a constant force produce on an object of fixed mass?

The Best From Conceptual Physics Alive!

Demo: Friction

Side 1
Chapter 26

5.4 Friction

Important Terms

air resistance
fluid

We discussed friction in Chapter 4. Friction is a force like any other force and affects motion. Friction acts on materials that are in contact with each other, and it always acts in a direction to oppose motion. When two solid objects come into contact, the friction is mainly due to irregularities in the two surfaces. When one object slides against another, it must either rise over the irregular bumps or else scrape them off. Either way requires force.

The force of friction between the surfaces depends on the kinds of material in contact and how much the surfaces are pressed together. For example, rubber against concrete produces more friction than steel against steel. That's why concrete road dividers have replaced steel rails; see Figure 5.5. The friction produced by a tire rubbing against the concrete is more effective in slowing the car than the friction produced by a steel car body sliding against a steel rail. Notice that the concrete divider is wider at the bottom to ensure that the tire of a sideswiping car will make contact with the divider before the steel car body does.

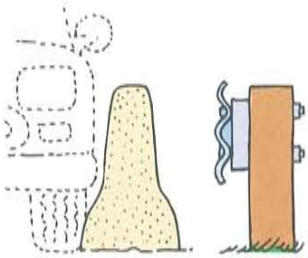


Figure 5.5 ▲
Cross-section view of a concrete road divider and a steel road divider. Which design is best for slowing an out-of-control, sideswiping car?

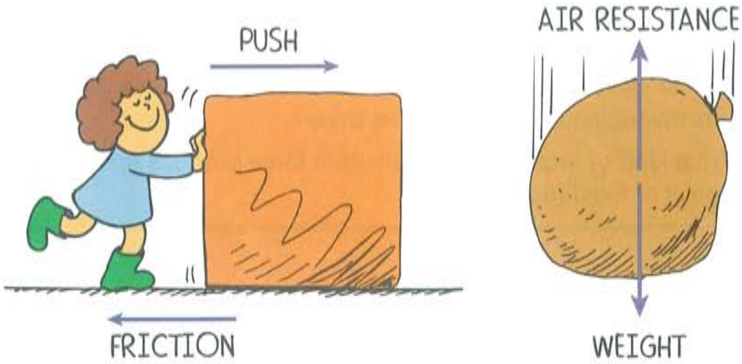
Friction is not restricted to solids sliding or tending to slide over one another. Friction also occurs in liquids and gases, both of which are called **fluids** (because they flow). Fluid friction occurs as an object pushes aside the fluid it is moving through. Have you ever tried running a 100-m dash through waist-deep water? The friction of liquids is appreciable, even at low speeds. **Air resistance,** which is the friction acting on something moving through air, is a very common form of fluid friction. You usually don't notice air resistance when walking or jogging, but you do notice it at the higher speeds that occur when riding a bicycle or skiing downhill.

When friction is present, an object may move with a constant velocity even when an outside force is applied to it. In such a case, the friction force just balances the applied force. The net force is zero, so there is no acceleration. For example, in Figure 5.6 the

Answers

1. The same force on twice the mass produces half the acceleration, or 1 m/s^2.
2. A constant force produces motion at a constant acceleration, in accordance with Newton's second law.

Figure 5.6 ▶
The direction of the force of friction always opposes the direction of motion. (Left) Push the crate to the right and friction acts toward the left. (Right) The sack falls downward and air friction acts upward.



crate moves with a constant velocity when the force pushing it just balances the force of friction. The sack will also fall with a constant velocity once the force due to air resistance balances the sack's weight.

Questions

1. Two forces act on a book resting on a table: its weight and the support force from the table. Does a force of friction act as well?
2. Suppose a high-flying jet cruises with a constant velocity when the thrust from its engines is a constant 80 000 N. What is the *acceleration* of the jet? What is the force of air resistance acting on the jet?

Important Terms

pascal
pressure

For tips on constructing your own bed of nails, contact Paul Robinson. e-mail: LaserPablo@AOL.com Fax: 916-344-3233

5.5 Applying Force—Pressure

No matter how you place a book on a table—on its back, upright, or even balancing on a single corner—the force of the book on the table is the same. You can check this by placing a book in any position on a bathroom scale. You'll read the same weight in all cases. Balance a book in different positions on the palm of your hand. Although the force is always the same, you'll notice differences in the way the

Answers

1. No, not unless the book tends to slide or does slide across the table. For example, if it is pushed toward the left by another force, then friction between the book and table will act toward the right. Friction forces occur only when an object tends to slide or is sliding.
2. The acceleration must be zero because the velocity is not changing—velocity is constant. Since the acceleration is zero, it follows from $a = F/m$ that the net force is zero. This means the force of air resistance must equal the engine's thrust. The air resistance is 80 000 N, and it acts in the direction opposite to the jet's motion.

book presses against your palm. These differences are due to differences in the area of contact for each case. The amount of force *per unit of area* is called **pressure.** More precisely, when the force is perpendicular to the surface area,

$$\text{pressure} = \frac{\text{force}}{\text{area of application}}$$

In equation form,

$$P = \frac{F}{A}$$

where P is the pressure and A is the area over which the force acts. Force, which is measured in newtons, is different from pressure, which is measured in newtons per square meter, or **pascals** (Pa). One newton per square meter is equal to one pascal.

You exert more pressure against the ground when you stand on one foot than when you stand on both feet. This is due to the decreased area of contact. Stand on one toe like a ballerina and the pressure is huge. The smaller the area supporting a given force, the greater the pressure on that surface.

You can calculate the pressure you exert on the ground when you are standing. One way is to moisten the bottom of your foot with water and step on a clean sheet of graph paper. Count the number of squares on the graph paper contained within your footprint. Divide your weight by this area and you have the average pressure you exert on the ground when standing on one foot. How will this pressure compare with the pressure you exert when you stand on two feet?

A dramatic illustration of pressure is shown in Figure 5.8. The author applies appreciable force when he breaks the cement block with the sledge hammer. Yet his friend (the author of the lab manual) sandwiched between two beds of sharp nails is unharmed. The friend is unharmed because much of the force is distributed over the more than 200 nails that make contact with his body. The combined surface area of this many nails results in a tolerable pressure that does not puncture the skin. CAUTION: This demonstration is quite dangerous. Do not attempt it on your own.

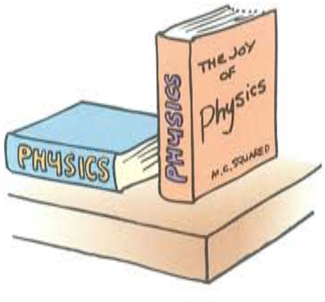


Figure 5.7 ▲
The upright book exerts the same force, but greater pressure, against the supporting surface.

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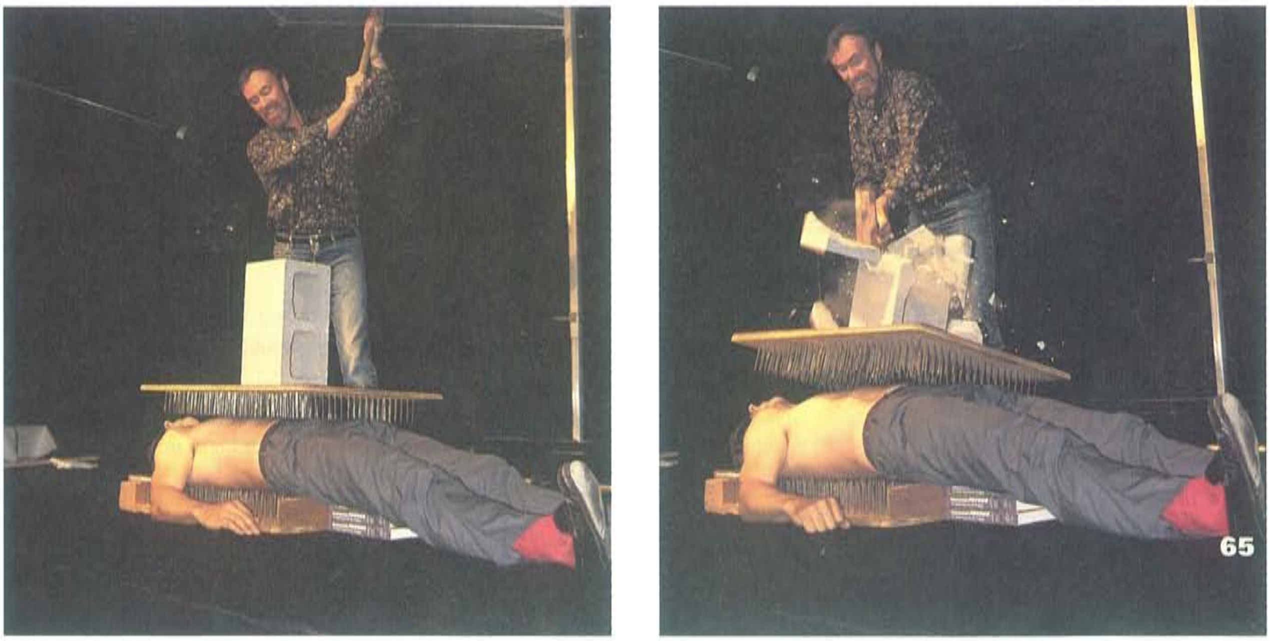
Pressure: The Bed of Nails

Side 1
Chapter 28

Figure 5.8 ▼
The author applies a force to fellow physics teacher Paul Robinson, who is bravely sandwiched between beds of sharp nails. The driving force per nail is not enough to puncture the skin. CAUTION: Do not attempt this on your own!



Questions

1. In attempting to do the demonstration shown in Figure 5.8, would it be wise to begin with a few nails and work upward to more nails?
2. The massiveness of the cement block plays an important role in this demonstration. Which provides more safety, a less massive block or a more massive one?

5.6 Free Fall Explained

igure 5.9 ▲
Galileo's famous demonstration.

Galileo showed that falling objects accelerate equally, regardless of their masses. This is *strictly* true if air resistance is negligible, that is, if the objects are in free fall. It is *approximately* true when air resistance is very small compared with the weight of the falling object. For example, a 10-kg cannonball and a 1-kg stone dropped from an elevated position at the same time will fall together and strike the ground at practically the same time. This experiment, said to be done by Galileo from the Leaning Tower of Pisa, demolished the Aristotelian idea that an object that weighs ten times as much as another should fall ten times faster than the lighter object. Galileo's experiment and many others that showed the same result were convincing. But Galileo couldn't say *why* the accelerations were equal. The explanation is a straightforward application of Newton's second law and is the topic of the cartoon "Backyard Physics." Let's treat it separately here.

Recall that mass (a quantity of matter) and weight (the force due to gravity) are proportional. A 2-kg bag of nails weighs twice as much as a 1-kg bag of nails. So a 10-kg cannonball experiences 10 times as much gravitational force (weight) as a 1-kg stone. The followers of Aristotle believed that the cannonball should accelerate at a rate ten times that of the stone, because they considered only the cannonball's ten-times-greater weight. However, Newton's second law tells us to consider the mass as well. A little thought will show that ten times as much force acting on ten times as much mass produces the same acceleration as the smaller force acting on the smaller mass. In symbolic notation,

$$\frac{F}{m} = \frac{\mathbf{F}}{\mathbf{m}}$$

mphasize that free fall means alling free of air resistance or ther constraints. Teach the hysics of free fall first. Then onsider non–free fall.

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ree-Fall Acceleration Explained

Side 1
Chapter 25

Answers

1. No, no, no! There would be one less physics teacher if the demonstration were performed with fewer nails. The resulting greater pressure would cause harm.
2. The greater the mass of the block, the smaller the acceleration of the block and bed of nails toward the friend. Much of the force wielded by the hammer goes into *breaking* the block. It is important that the block be massive and that it break upon impact.


BACKYARD PHYSICS
IF I DROP THE BAG OF CLOTHESPINS AND THE SINGLE PIN AT THE SAME TIME, WHICH WILL FALL TO THE GROUND FIRST?
THAT'S EASY! THE BAG OF CLOTHESPINS IS HEAVIER, WHICH MEANS GRAVITY PULLS ON IT WITH MORE FORCE. SO THE BAG OF PINS WILL ACCELERATE MORE AND HIT THE GROUND FIRST!
PHYSICS PHYSICS PHYSICS
NOT TRUE! THE BAG OF CLOTHESPINS HAS MORE MASS, WHICH IS TO SAY, HAS MORE INERTIA ... IT WILL BE LESS RESPONSIVE TO GRAVITY AND LAG BEHIND THE SINGLE PIN!
SO THE SINGLE PIN WILL HIT THE GROUND FIRST!
SIGH
SORRY GANG ... A TIE SCORE
HOW COME???
PLUNK!
PLINK!
SINCE THE BAG HAS BOTH A GREATER WEIGHT AND A GREATER INERTIA, ONE OFFSETS THE OTHER!
(WEIGHT / MASS)BAG = (WEIGHT / MASS)PIN = g
THE ACCELERATION IS EQUAL FOR BOTH!
OF COURSE

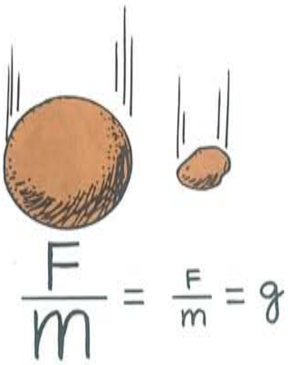


Figure 5.10 ▲
The ratio of weight (F) to mass (m) is the same for the 10-kg cannonball and the 1-kg stone.

where F stands for the force (weight) acting on the cannonball, and m stands for the correspondingly large mass of the cannonball. The small F and m stand for the smaller weight and smaller mass of the stone. We see that the *ratio* of weight to mass is the same for these or any objects. All freely falling objects undergo the same acceleration at the same place on the earth. In Chapter 2 we introduced the symbol g for the acceleration.

We can show the same result with numerical values. The weight of a 1-kg stone is 9.8 N at the earth's surface. The weight of a 10-kg cannonball is 98 N at the earth's surface. The force acting on a falling object is the force due to gravity—the object's weight. Using Newton's second law, the acceleration of the stone is

$$a = \frac{F}{m} = \frac{\text{weight}}{m} = \frac{9.8\text{ N}}{1\text{ kg}} = \frac{9.8\text{ kg}\cdot\text{m/s}^2}{1\text{ kg}} = 9.8\text{ m/s}^2 = g$$

and the acceleration of the cannonball is

$$a = \frac{F}{m} = \frac{\text{weight}}{m} = \frac{98\text{ N}}{10\text{ kg}} = \frac{98\text{ kg}\cdot\text{m/s}^2}{10\text{ kg}} = 9.8\text{ m/s}^2 = g$$

In the famous coin-and-feather-in-a-vacuum-tube demonstration discussed in Chapter 2, the reason for the equal accelerations was not discussed. Now we know that both freely falling objects fall with the same acceleration because the net force on each object is only its weight, and the ratio of weight to mass is the same for both.

Compare this to the ratio of circumference to diameter for circles of different sizes:

$$\frac{C}{D} = \frac{C}{D} = \pi$$

Question

If you were on the moon and dropped a hammer and a feather from the same elevation at the same time, would they strike the surface of the moon at the same instant?

5.7 Falling and Air Resistance

Important Terms

terminal speed
terminal velocity

Interactive Physics™ Simulations: 8 Parachutist

Parachutists and sky divers speak about TV—terminal velocity.

The feather and coin fall with equal accelerations in a vacuum, but quite unequally in the presence of air. When air is let into the glass tube and it is again inverted and held upright, the coin falls quickly while the feather flutters to the bottom. Air resistance diminishes the net forces acting on the objects. The net force decreases a tiny bit for the coin and a lot for the feather. The downward acceleration for the feather is very brief because the air resistance builds up quickly and counteracts its tiny weight. The feather does not have to fall very long or very fast for this to happen. When the air resistance on the feather equals the weight of the feather, the net force is zero and no further

Answer

Yes. Astronaut David Scott did this exact experiment! On the moon, the hammer and feather weigh only one-sixth of their earth weight, and there is no air to provide friction. The ratio of moon-weight to mass for each object is the same, and they both accelerate at (1/6)g.

Figure 5.11
Terminal speed is reached for the sky divers when air pressure equals weight.

acceleration occurs. Acceleration terminates: the feather has reached its **terminal speed.** If we are concerned with direction, which is down for falling objects, we say the feather has reached its **terminal velocity.**

Air resistance does not have as much effect on the coin. At slow speeds, the force of air resistance is very small compared with the weight of the coin, and its acceleration is only slightly less than the acceleration of free fall, g. The coin might have to fall for several seconds before its speed is great enough for air resistance to equal and cancel its weight. Its speed at this point, perhaps as much as 200 km/h, would no longer increase. The coin reaches its terminal speed.

The terminal speed for a sky diver varies from about 150 to 200 km/h, depending on the weight and orientation of the body. A heavier person will attain a greater terminal speed than a lighter person. The greater weight is more effective in "plowing through" air. Body orientation also makes a difference. More air is encountered when the body is spread out and surface area is increased, like that of the flying squirrel in Figure 5.12. Terminal speed can be controlled by variations in body orientation. A heavy sky diver and a light sky diver can remain in close proximity to each other if the heavy person spreads out like a flying squirrel while the light person falls head or feet first. A parachute greatly increases air resistance, and cuts the terminal speed down to 15 to 25 km/h, slow enough for a safe landing.

If you hold a baseball and tennis ball at arm's length and release them at the same time, you'll see them strike the floor at the same time. But if you drop them from the top of a building, you'll notice

With air resistance R, the acceleration is

$$a = \frac{F_{net}}{m} = \frac{\text{weight} - \text{resistance}}{m} = \frac{mg - R}{m} = g - \frac{R}{m}$$

Note that with air resistance, the acceleration will always be less than g by the amount R/m.

Figure 5.12
The flying squirrel increases its area by spreading out. This increases air resistance and decreases the speed of its fall.

Question

If a heavy person and a light person open their parachutes together at the same altitude and each wears the same size parachute, who will reach the ground first?

Answer

The heavy person will reach the ground first. Like a feather, the light person reaches terminal speed sooner, while the heavy person continues to accelerate until a greater terminal speed is reached. The heavy person moves ahead of the light person, and the separation continues to increase as they descend.

The Best From Conceptual Physics Alive!

Falling & Air Resistance

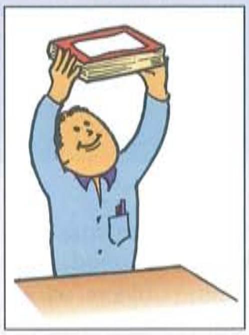
Side 1
Chapter 27

The terminal speed for a baseball is about 45 m/s (100 mi/h); for a tennis ball it is about 33 m/s (75 mi/h).

DOING PHYSICS

Air Resistance

If you drop a sheet of paper and a book side by side, the book will fall faster because of its greater weight relative to the air resistance. If you place the paper against the bottom surface of the horizontally held book and drop them at the same time, it is no surprise that they will hit the floor at the same time. The book simply pushes the paper with it as it falls. Repeat this with the paper on top of the book. How do the accelerations of the book and paper compare?



Activity

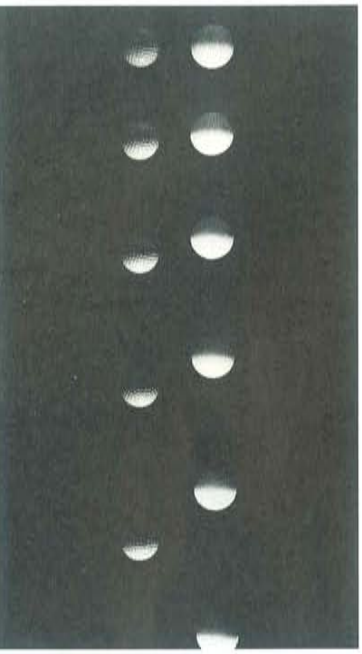


Figure 5.13 ▲
A stroboscopic photo of a golf ball and a Styrofoam® ball falling in air. The weight of the heavier golf ball is more effective in overcoming air resistance, so its acceleration is greater. Will both ultimately reach a terminal speed? Which will do so first? Why?

Both balls will reach a terminal speed. The foam ball will reach it first because R/m (see equation in teacher note on previous page) is greater for it, as its mass is smaller.

the heavier baseball strikes the ground first. This is due to the buildup of air resistance at higher speeds (like the parachutists in the question). At low speeds, air resistance is often negligible, but at high speeds, it can make quite a difference. The effect of air resistance is more pronounced on the lighter tennis ball than on the heavier baseball, so the acceleration of the fall is less for the tennis ball. The tennis ball behaves more like a parachute than the baseball does.

When Galileo reportedly dropped the objects of different weights from the Leaning Tower of Pisa, the heavier object *did* get to the ground first. However, the time difference was only a split second, rather than the pronounced time difference expected by the followers of Aristotle. The behavior of falling objects was never really understood until Newton announced his second law of motion.

Isaac Newton truly changed our way of seeing the world.

■ Question

If the force of air resistance is the same for a falling baseball and a falling tennis ball, which will have the greater acceleration?

■ Answer

Don't say "the same"! It's true the air resistance is the same for each, but that doesn't mean the net force is the same for each, or that the ratio of net force to mass is the same for each. The heavier baseball has the greater net force, and greater net force per mass, just as the heavier parachutist previously considered. Convince yourself of this by considering the upper limit of air resistance, that is, when air resistance is equal to the weight of the tennis ball. What would the tennis ball's acceleration be? It would be zero. But when this amount of air resistance acts on the heavier baseball, do you see that the baseball still accelerates? And with more thought, do you see that the baseball has the greater acceleration even when the air resistance is less than the weight of the tennis ball?

5 Chapter Review

For fuller explanations, see the TE notes in the front of this book.

Concept Summary

An object accelerates—changes speed and/or direction—when a net force acts on it.

- The acceleration of an object is directly proportional to the net force acting on it.
- The acceleration of an object is inversely proportional to the mass of the object.
- Acceleration equals net force divided by mass.
- Acceleration is in the same direction as the net force.

When an object moves with constant velocity while an applied force acts on it, an equal and opposite force, usually friction, must also act to balance the applied force.

The application of a force over an area produces pressure.

- When the force is perpendicular to the surface area, the pressure equals the force divided by the area over which it acts.

The acceleration of all objects in free fall is the same, regardless of their mass.

- When air resistance is present, a falling object accelerates only until it reaches its terminal speed.
- At terminal speed, the force of air resistance balances the force of gravity.

Important Terms

air resistance (5.4)
fluid (5.4)
inversely (5.2)
Newton's second law (5.3)
pascal (5.5)
pressure (5.5)
terminal speed (5.7)
terminal velocity (5.7)

Review Questions

Recall of key chapter ideas

1. Distinguish between the relationship that defines acceleration and the relationship that states how it is produced. (5.1) $a = \Delta v/\Delta t$; $a = F/m$
2. What is meant by the net force that acts on an object? (5.1) Resultant of all applied forces
3. Suppose a cart is being moved by a certain net force. If the net force is doubled, by how much does the cart's acceleration change? (5.1) The acceleration doubles.
4. Suppose a cart is being moved by a certain net force. If a load is dumped into the cart so its mass is doubled, by how much does the acceleration change? (5.2) The acceleration decreases by half.
5. Distinguish between the concepts *directly proportional* and *inversely proportional.* Support your statement with examples. (5.1–5.2) Increasing one increases other by same factor; decreases other by same factor.
6. State Newton's second law in words and then in the form of an equation. (5.3) Acceleration = force per mass; $a = F/m$
7. How much force does a 20 000-kg rocket develop to accelerate 1 m/s^2? (5.3) 20 000 N
8. What is the cause of friction, and in what direction does it act with respect to the motion of a sliding object? (5.4) Surface irregularities; opposes motion
9. If the force of friction acting on a sliding crate is 100 N, how much force must be applied to maintain a constant velocity? What will be the net force acting on the crate? What will be the acceleration? (5.4) 100 N; zero net force; zero acceleration
10. Distinguish between force and pressure. (5.5) Force—a push or pull; pressure = force/area
11. Which produces more pressure on the ground, a person standing up or the same person lying down? (5.5) Person standing—contact area is smaller

12. The force of gravity is twice as great on a 2-kg rock as on a 1-kg rock. Why does the 2-kg rock not fall with twice the acceleration? (5.6) Twice the force acts on twice the mass.

13. Why do a coin and a feather in a vacuum tube fall with the same acceleration? (5.7) Both have the same (weight/mass) ratio.

14. Why do a coin and a feather fall with different accelerations in the presence of air? (5.7) Different $(Wt - R)/m$ ratios

15. How much air resistance acts on a 100-N bag of nails that falls at its terminal speed? (5.7) 100 N

16. How do the air resistance and the weight of a falling object compare when terminal speed is reached? (5.7) Air resistance = weight

17. All other things being equal, why does a heavy sky diver have a terminal speed greater than a light sky diver? What can be done so that both terminal speeds are equal? (5.7) (Air resistance/weight) is less; vary area

18. What is the net force acting on a 25-N freely falling object? What is the net force when the object encounters 15 N of air resistance? When it falls fast enough to encounter 25 N of air resistance? (5.6–5.7) 25 N downward; 10 N downward; 0 N

Activity

1. Drop two balls of different weights from the same height, and for low speeds, they practically fall together. Will they roll together down the same inclined plane? If each is suspended from the same length string, made into a pendulum, and then displaced through the same angle, will they swing back and forth in unison? Try it and see. Both roll and swing together

Plug and Chug

Math reinforcement—conceptual development through applied problem solving

1. Calculate the acceleration of a 2000-kg, single-engine airplane just before takeoff when the thrust of its engine is 500 N. $a = F/m = 500\ \text{N}/2000\ \text{kg} = 0.25\ \text{m/s}^2$

2. Calculate the acceleration of a 300 000-kg jumbo jet just before takeoff when the thrust for each of its four engines is 30 000 N. $a = F/m = 4\ (30\ 000\ \text{N})/300\ 000\ \text{kg} = 0.4\ \text{m/s}^2$

3. **a.** Calculate the acceleration if you push with a 20-N horizontal force on a 2-kg block on a horizontal friction-free air table. $a = F/m = 20\ \text{N}/2\ \text{kg} = 10\ \text{m/s}^2$

   b. What acceleration occurs if the friction force is 4 N? $a = (20\ \text{N} - 4\ \text{N})/2\ \text{kg} = 8\ \text{m/s}^2$

4. Calculate the horizontal force that must be applied to produce an acceleration of 1 *g* for a 1-kg puck on a horizontal friction-free air table. $F = ma = (1\ \text{kg})(9.8\ \text{m/s}^2) = 9.8\ \text{N}$ (10 N rounded)

5. Calculate the horizontal force that must be applied to produce an acceleration of 1.8 *g* for a 1.2-kg puck on a horizontal friction-free air table. $F = ma = (1.2\ \text{kg})(1.8)(9.8\ \text{m/s}^2) = 21.2\ \text{N}$ (21 rounded)

Think and Explain

Conceptual development through applied critical thinking

1. What is the difference between saying that one quantity is proportional to another and saying it is equal to another? Prop—changes by same factor; Equal—quantities same

2. If an object has no acceleration, can you conclude that no forces are exerted on it? Explain. No; you *can* conclude no *net* force acts on it.

3. What is the acceleration of a rock at the top of its trajectory when thrown straight upward? Explain whether or not the answer is zero by using the equation $a = F/m$ as a guide to your thinking. g; $a = F/m = mg/m = g$, certainly not zero

4. A rocket fired from its launching pad not only picks up speed, but its acceleration also increases significantly as firing continues. Why is this so? (*Hint:* About 90% of the mass of a newly launched rocket is fuel.) As mass decreases, acceleration increases.

5. When blocking in football, why does a defending lineman often attempt to get his body under that of his opponent and push upward? What effect does this have on the friction force between the opposing lineman's feet and the ground? Reduces both ground contact and friction

6. Why does a sharp knife cut better than a dull knife? Small cutting area applies greater pressure

7. An aircraft gains speed during takeoff due to the constant thrust of its engines. When is the acceleration during takeoff greatest—at the beginning of the run along the runway or just before the aircraft lifts into the air? Think, then explain. At the beginning, before air drag decreases the acceleration

8. As a sky diver falls faster and faster through the air (before reaching terminal speed), does the net force on her increase, decrease, or remain unchanged? Does her acceleration increase, decrease, or remain unchanged? Defend your answers. Decreases; decreases; resisted by air drag

9. After she jumps, a sky diver reaches terminal speed after 10 seconds. Does she gain more speed during the first second of fall or the ninth second of fall? Compared with the first second of fall, does she fall a greater or a lesser distance during the ninth second? Gains more v in 1st sec; more d in 9th sec

10. A regular tennis ball and another one filled with heavy sand are dropped at the same time from the top of a high building. Your friend says that even though air resistance is present, both balls should hit the ground at the same time because they are the same size and "plow through" the same amount of air. What do you say? See footnoted ans to last question in chapter.

Think and Solve

Math reinforcement—variable substitution and equation solving

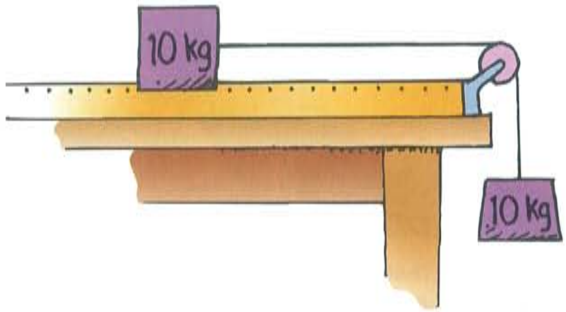
1. A horizontal force of 100 N is required to push a crate across a factory floor at a constant speed. What is the net force acting on the crate? What is the force of friction acting on the crate? Zero (because $a = 0$); 100 N

2. If a four-engine jet accelerates down the runway at 2 m/s^2 and one of the jet engines fails, how much acceleration will the other three produce? 3/4 F means 3/4 a = 1.5 m/s^2

3. What will be the acceleration of a sky diver when air resistance is half the weight of the sky diver? $a = F/m = (mg - 0.5mg)/m = 0.5g$

4. If a loaded truck that can accelerate at 1 m/s^2 loses its load and has three-fourths of the original mass, what acceleration can it attain from the same driving force?
4/3 or 1.33 m/s^2

5. A 10-kg mass on a horizontal friction-free air track is accelerated by a string attached to another 10-kg mass hanging vertically from a pulley as shown. What is the force due to gravity in newtons of the hanging 10-kg mass? What is the acceleration of the system of both masses? 98 N (100 N rounded); a = 98 N/(10 kg + 10 kg) = 4.9 m/s^2 (5 m/s^2 rounded)



6. Suppose the masses described in the preceding problem are 1 kg and 100 kg, respectively. Compare the accelerations when they are interchanged, that is, for the case where the 1-kg mass dangles over the pulley, and then for the case where the 100-kg mass dangles over the pulley. What does this indicate about the maximum acceleration of such a system of masses? $a = (1\text{ kg} \times g)/(1\text{ kg} + 100\text{ kg}) = 1/101\ g$; $a = (100\text{ kg} \times g)/(100\text{ kg} + 1\text{ kg}) = 100/101\ g = 0.99g$; Maximum acceleration = g